

Original

Evaluation of deep venous thrombosis using dual-energy CT

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Running Title

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Abstract

Purpose: To evaluate deep vein thrombosis (DVT) using virtual monochromatic imaging (VMI) with dual-energy analysis

Materials and Methods: We used data from 29 patients who were imaged using the pulmonary embolism (PE)/DVT protocol at Showa University Hospital and evaluated the diagnostic utility of VMI with dual-energy analysis. In VMI, we compared computed tomography (CT) values of the femoral veins on both sides and the surrounding muscle tissues at 40 Kev and conventional image; two radiologists performed visual evaluation in three stages. We also evaluated CT values of thrombi for cases with DVT.

RESULTS: We conducted a retrospective cohort study on 29 (18 males and 11 females) patients with a mean age of 66.8 (range: 31–86) years. DVT was confirmed in four of the subjects (13.7%). Visual evaluation confirmed a significant difference at 40 Kev and conventional image (2.76 vs 1.81; $p < 0.05$).

CT values in the femoral vein were 274.67 (range: 186.35–63.31)

Hounsfield units (HU) at 40 Kev and 109.46 (range: 74.54–155.66) HU at conventional image, confirming a significant difference ($p < 0.05$).

Contrast-to-noise ratios (CNRs) [(femoral vein CT value – adductor muscle CT value)/adductor muscle standard deviation (SD)] were 11.77 (range:

3.93–26.33) HU at 40 Kev and 9.87 (range: 1.28–27.56) HU at conventional image, confirming a significant difference ($p < 0.05$).

The thrombus / femoral vein ratio (CT value) was 0.34 at 40 Kev and 0.59 at conventional image, and their CNR was 17.52 at 40 Kev and 4.32 at conventional image, both showing significant differences.

CONCLUSION: Low-voltage contrast CT is useful for enhancing images of veins and may also be very useful in detecting DVT.

Key words

dual-energy. computed tomography. monochromatic imaging.
deep vein thrombosis.

Introduction

Dual-energy CT (DE-CT) uses two different tube voltages and is able to prepare virtual monochromatic X-ray images at arbitrary energy.

Various clinical applications are expected because of this technology, including reduction in artifacts by high-energy imaging, reduction in the amount of contrast agent using low-energy images, and reduction in the exposure to radiation. However, changes in energy affect noise standard deviation (SD) and artifacts etc. This technology is applied for bone mineral

density quantification and bone removal using simple X-ray images, which are commonly used. Many studies have been conducted on DE-CT imaging since a report using this method for bone mineral density quantification in 1977 (1). Initially, two scans were required to obtain data. In 1988, a new clinical device allowed for imaging with one scan, but its use was not widespread because of the long imaging time, noise due to poorly regulated scattered radiation in low tube-voltage imaging, deviation in the position, and beam hardening artifacts, etc., which were difficult to overcome. In 2006, Siemens launched a CT device that produced images using two X-ray tubes, leading to newfound focus on DE-CT imaging. Subsequently, this technology was advanced with each manufacturer's unique characteristics and is now sufficient for clinical use.

Recently, Siemens began to equip single-source CT devices with a new technology called “twin-beam dual energy,” which allowed routine dual-energy tests for the first time. “Twin-beam dual energy” obtains image data without any temporal or spatial error by simultaneously scanning with two different types of energies (high and low). These two types of data allow for extraction of contrast agent components; differentiation of tissues, such as bones, blood vessels, and calcification; and dual-energy imaging that visualizes information, for example, in the compositional analysis of

kidney stones, making routine tests with high resolution and low radiation exposure possible.

Pulmonary embolism (PE) that frequently develops from DVT in the lower extremity is a well-known sequela and can even lead to death (2, 3). If untreated, the mortality rate of PE is 30%; however, if it is treated, the mortality rate decreases to 5%–8% (4, 5). Symptoms of DVT are diverse, making it difficult to diagnose based on clinical findings only (6); therefore, an evaluation based on imaging would be useful in making a definitive diagnosis (7, 8). To obtain good images of the veins, appropriate scanning parameters and timing of the imaging are important but can be challenging. Thus, additional imaging is required for evaluating the presence of DVT in 3.1%–15.2% of the cases (7, 10–13).

DE-CT virtual monochromatic imaging (VMI) has a high CT value for iodine during low-voltage imaging; accordingly, if an iodine contrast agent is used, the blood vessels will show a high concentration of iodine, which improves visualization of the blood vessels. Iodine concentration can improve visualization of not only the arteries but also the veins. Because the CT value does not increase with the thrombus, it creates a good contrast between strongly stained veins and the thrombus, making a diagnosis of DVT easier. Therefore, in this study, we examined whether DE-CT VMI

low-voltage imaging was useful in diagnosing DVT. We compared images at conventional image with those at 40 Kev.

Materials and methods

We used data of 29 patients who were imaged using the PE/DVT protocol at Showa University Hospital. The study period was from April 1, 2017, to July 30, 2017. We compared CT values of the femoral veins on both sides and the surrounding muscle tissues at 40 Kev and conventional image and calculated contrast-to-noise ratios (CNR). CNRs were calculated using the following equation:

$$\text{CNR} = (\text{VV} - \text{AD})/\text{N}$$

Where VV and AD are CT values of the femoral veins and adductor muscles, respectively, and N is the SD of the adductor muscles. The region of interest (ROI) for the adductor muscle group was set at a diameter of ≥ 1 cm, while that for the femoral veins was set at a diameter one-half or more of the diameter of the femoral veins. In addition, we calculated the ratio of CT values with the thrombus and the femoral vein on the opposite side of the thrombus for subjects with DVT. Two radiologists made a visual evaluation in three stages (3, good; 2, equivocal; and 1, poor).

Diagnosis of DVT was based on complete or partial contrast defects in at least two continuous axial planes (8) at 40 Kev (venous phase). To avoid subjective bias in the radiologists' evaluation, evaluation was done after diagnosing DVT with the method described on the left.

Calculations and Statistical Analysis

We used the Wilcoxon rank-sum test to compare visual evaluations by two radiologists at 40 Kev and conventional image. We also used paired *t*-test to compare femoral vein CT values, adductor muscle CT values, CNRs, and thrombus CT values at 40 Kev and conventional image. Statistical calculation was performed using JSTAT 2012 and Microsoft Excel 2016. We considered $p < 0.05$ to be statistically significant.

Results

We conducted a retrospective cohort study with 29 (18 males and 11 females) patients, with a mean age of 66.8 (range: 31–86) years. DVT was confirmed in four subjects (13.7%). The images did not show any strong artifacts by movement or clear indication of a lack of contrast agent due to leakage. We calculated the mean of the visual evaluations, noise evaluations, and total scores of radiologists A and B (Table 1) and found a

significant difference in visual evaluations at 40 Kev and conventional image (2.76 vs 1.81; $p < 0.05$).

CT values in the femoral vein were 274.67 (range: 186.35–63.31) Hounsfield units (HU) at 40 Kev and 109.46 (range: 74.54–155.66) HU at conventional image, confirming a significant difference ($p < 0.05$). CT values of the adductor muscles were 107.05 (range: 63.31–146.09) HU at 40 Kev and 67.12 (range: 39.69–91.59) HU at conventional image, showing a significant difference ($p < 0.05$).

Adductor muscle SD values were 15.45 (range: 9.26–28.1) HU at 40 Kev and 4.69 (range: 2.81–8.54) HU at conventional image, showing a significant difference ($p < 0.05$). Contrast-to-noise ratios (CNRs) [(femoral vein CT value – adductor muscle CT value)/adductor muscle standard deviation (SD)] were 11.77 (range: 3.93–26.33) HU at 40 Kev and 9.87 (range: 1.28–27.56) HU at conventional image, confirming a significant difference ($p < 0.05$).

The thrombus / femoral vein ratio (CT value) was 0.34 at 40 Kev and 0.59 at conventional image, and their CNR was 17.52 at 40 Kev and 4.32 at conventional image, both showing significant differences.

Discussion

PE frequently occurs with lower extremity DVT and is a well-known sequela that could lead to death (2, 3). As discussed earlier, though CT can be performed to diagnose DVT, additional imaging is required to evaluate DVT in 3.1%–15.2% cases (7, 10-13).

Generally, when the tube voltage is reduced, tissue contrast improves but noise increases. Many studies have demonstrated the utility of virtual monochromatic X-ray imaging with low energy using DE-CT analysis, e.g., evaluations of endoleak following aortic stent placement and pulmonary artery thromboembolism. (14–21). In this study, we used differences in contrast and noise from two different energies—low energy (40 Kev) and high energy (conventional image)—in DE-CT VMI to perform a within-case comparison.

We examined differences in contrast and noise at 40 Kev and conventional image and found significant differences. At conventional image, CNR decreased ($p < 0.05$). However, contrast between the femoral vein and background (we used the adductor muscles as the baseline) varied in each case; there was even a case in which the CT value in the femoral vein was lower than that in the adductor muscles (Fig. 1). In such a case, it is difficult to visually evaluate DVT. In addition, CT values of the femoral veins and adductor muscles were close in many cases; therefore, many

cases had a low visual evaluation score at conventional image. Hence, we needed to focus on the fact that, even in cases where DVT evaluation at conventional image was difficult, visual evaluation was improved by lowering the energy (40 Kev).

In DVT cases, CNRs were improved at 40 Kev when visualizing the thrombi (Table 2). In addition, the mean visual evaluation was 3.0 at 40 Kev and 1.9 at conventional image. Visualization of DVT improves as the surrounding veins are emphasized. During virtual low-voltage imaging, the CT value of the thrombus is high, but the change is not as high as in iodine; hence, the difference in CT values between the thrombus and contrasted veins is high. Therefore, the contrast between the thrombus and contrasted veins is high, improving visualization.

Limitations of this study are as follows. First, the number of cases with DVT is small. A larger scale DVT survey and examination of the actual improvement in DVT diagnosis are needed.

Second, mean scores of visual evaluations by the two radiologists were inconsistent (radiologist A, mean scores of 2.41 and radiologist B, mean scores of 2.16). However, both evaluations at 40 Kev were better than those at conventional image ($p < 0.05$).

Conclusion

Low-voltage contrast CT is useful in enhancing images of veins and may also be useful in detecting DVT.

		40keV	conventional image	
Visual evaluation	Radiologist A	2.97	1.86	p<0.05
	Radiologist B	2.55	1.76	p<0.05
	Total score of two radiologists	2.76	1.81	p<0.05
Femoral vein CT value (HU)		274.67	85.77	p<0.05
Adductor muscle CT value (HU)		107.05	60.98	p<0.05
Adductor muscle SD value		15.45	6.48	p<0.05
CNR		11.7	4.1	p<0.05

Table 1

Comparison of visual evaluations, CT values, and CNRs at 40 and conventional image

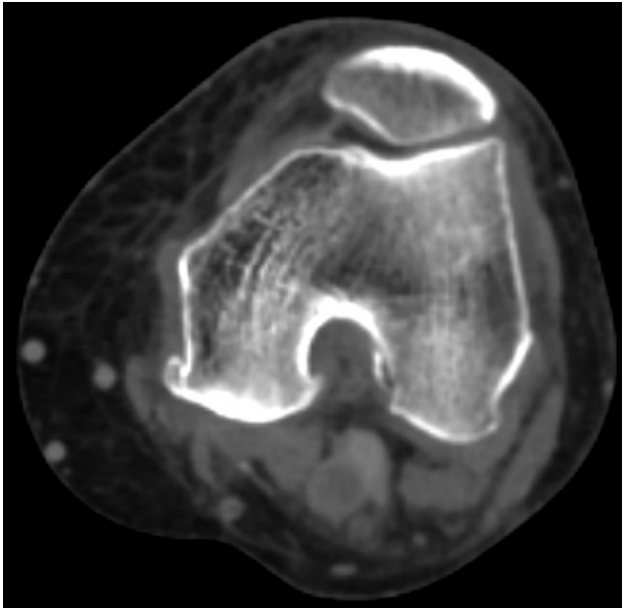
At 40 Kev, femoral vein CT values were higher than those at conventional image, CNRs were high, and visual evaluations improved.

	Thrombus CT value (40keV)	Femoral vein CT value (40keV)	Thrombus CT value (conventional image)	Femoral vein CT value (conventional image)	Thrombus/vein (40keV)	Thrombus/vein (conventional image)	CNR((Femoral vein – thrombus)/SD)(40keV)	CNR((Femoral vein – thrombus)/SD) (conventional image)
Patient A	93.62	226.2	60.07	90.48	0.41	0.66	7.97	1.83
Patient B	75.11	250.98	49.99	100.392	0.30	0.50	18.42	5.28
Patient C	95.75	343.8	74.88	137.52	0.28	0.54	26.79	6.76
Patient D	102.79	289.98	78.14	115.992	0.35	0.67	16.94	3.43

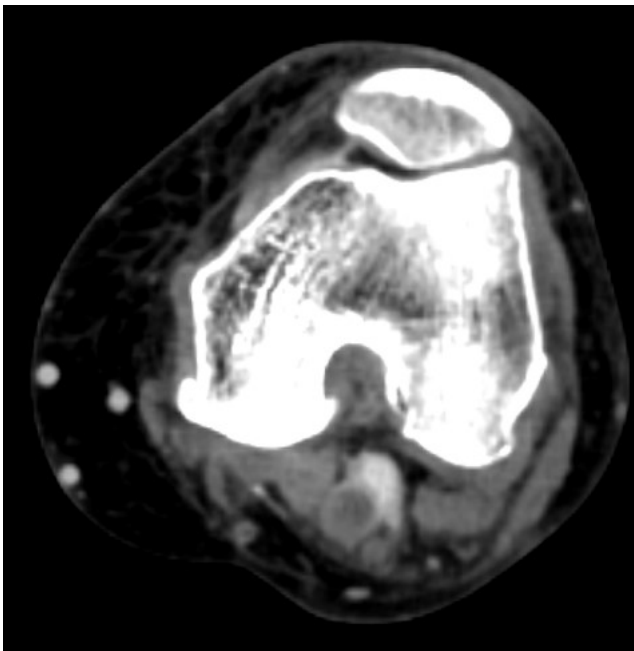
Table 2

CT and CNR values for four subjects with DVT

At 40 Kev, the contrast between the thrombus and the femoral vein was better than that at conventional image.



A



B

Figure 1

A: Conventional image; B: 40 Kev

A: CT value in the femoral vein was low (100.39 HU), and the contrast with surrounding tissues was good. It was difficult to evaluate the presence or absence of DVT.

B: CT value in the femoral vein was high (250.98 HU), and the contrast with surrounding tissues was good. It was easy to evaluate the presence or absence of DVT.

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